An Empirical Modelling approach to Systems Modelling and Simulation

Abstract

This paper attempts to illustrate how systems modelling and simulation can be viewed from an empirical modelling perspective. A discussion on how the concept of agency and dependencies can be used in modelling physical properties of various artefacts seeks to demonstrate the potentials of empirical modelling in the field of engineering systems modelling. A case study involving a model of a pendulum is also presented which demonstrates the practical aspects of this theme.

1 Introduction

Concurrent systems involve a wide collection of application areas ranging from high performance distributed computing systems to sophisticated mobile robotic apparatus. Due to the high level of complexity that they often incorporate, and due to the great level of understanding that they require, such systems usually go through a modelling or a simulation phase before they are actually built. This allows the engineers or the developers with the aid of computer simulations, to experiment and interact with the artefact and analyse its behaviour in a sufficient level of detail before its actual construction

Systems modelling and simulation has proved to be a very useful methodology within the engineering community. Especially for dynamic systems which are hard to analyse and visualise, modelling has become a mandatory element in the life cycle of such products. Engineers have widely adopted models both for practical and conceptual reasons. For example, a model can be used to predict the performance of a newly designed system, or even it can be used to examine the impact of altering certain components of the system. In addition, building a model of the actual artefact to be constructed allows the system designer to eventually act as a system user. Switching between the two roles enables the designer to examine further issues which could not be observed otherwise. Most importantly the designer can determine whether or not the artefact meets the required functionality as specified by the system design. On the flip side, it can comprise a means to ensure that the system was correctly engineered, as well as to identify any faults or omissions that could be present in that artefact's blueprint. This is the main reason why usually the modelling phase coexists in parallel to the design phase.

In this paper the author aims to demonstrate how Empirical Modelling can be adopted as a powerful concept in engineering and in particular as a means to enhance the modelling and simulation of engineering and physical systems.

2 The Empirical Modelling approach

It is possible for computer models to be effectively used in the analysis of engineering systems without having the need to closely reflect their architectural and physical characteristics (Beynon, Bridge and Yung 1992). Such models can successfully embody and illustrate the behaviour of an artefact without having to emulate the underlying driving mechanisms. It therefore simplifies things as far as the construction of the model is concerned and on the other hand it allows the designer to focus on the important aspect of the simulation being the interaction with the modelled artefact.

Empirical Modelling (EM) involves tools and techniques which enable the construction of computer based artefacts that embody what is directly experienced.

2.1 An agent-based discipline

There exist two different perspectives for modelling concurrent systems: The event-oriented approach and the interaction or activity-oriented approach. The event-oriented approach focuses on the overall system's abstract behaviour whereas the activity-oriented approach is mostly concerned with the interactions of the individual system components (Nance, 1981). It is hence evident that in order to present a comprehensive view of such a model both perspectives must be combined such that to provide a concrete analysis of the system.

By adopting the EM agent-based paradigm enables system designers to exploit both approaches (Beynon and Norris 1990). Agents which are considered as a notion of abstracting the high-level behaviour of any subsystem are used to describe the principal system components. Agents can be identified as a first step within a system along with the various observables which they are able to respond to. Consequently the stimulus-response behaviour of the agents needs to be specified according to the desired system functionality.

For accomplishing the above a definitive (definition-based) language LSD (Beynon 1987) is used to describe the system's behaviour. LSD uses a function based fashion to specify the different operations in terms of the system variables. This definitive notation classifies the observables that can be found within a particular system according to their functionality in respect to the agents and their possible states.

Formal structured mathematical and engineering methodologies require that mathematical equations are set before the interaction between subsystems or the overall system behaviour can be considered. In practice though, and especially in the area of system modelling, such underlying mathematical mechanisms are not mandatory to encapsulate the behaviour of a system and preview its performance. Such methodologies even fail to deliver some abstract system behaviour in cases where only a high-level view of the system is required.

In contrast to the above, LSD as a novel approach, provides a way to simplify the specification of dynamic systems' modelling. This agent-oriented approach appears to map well on complex engineering and physical systems mostly because such systems are built using smaller components or subsystems at different levels. Each of those components can be treated as a different entity that acts autonomously and therefore this method provides the ability to the designer to view each entity separately, or to observe the collective functionality of a larger subsystem.

2.2 Potential users

Using definitive notations and models allows scope for several categories of potential users to be considered. Perhaps the most obvious user of such a model is the engineer responsible for the construction of the actual system. Such user would like to review the system properties through a computer model in order to ensure that the functional aspects of the system will be fulfilled when the actual construction takes place. Next there is the proposed user or operator of the system modelled. A designer may want the real life user of the artefact to interact with a simulation in order to verify that the user-artefact interaction is smooth and effective. Such simulations can also be used for training purposes, for example to train pilots by using a model of the cockpit of an aircraft. There can be many other types of users including external and internal system observers.

Using definitive notations or scripts to build models, enables the model builder to accommodate several different perspectives or ways to interact with a single artefact. Different dependencies can be defined according to the needs and the purpose of each kind of user. Some dependencies may not appear to be meaningful for one category of users (say the architects) but they may be extremely helpful for some other (observers). Therefore by just manipulating the dependencies inside a model it is possible to have different kinds of users interacting with the same model and viewing it from different perspectives.

2.3 EM in Concurrent Engineering

Concurrent engineering is a related field where EM models also have potential use. As an area where the best of both specialisation and integration are required, many people that possess different skills must collaborate in order to achieve the best possible outcome. However the coordination of this effort as well as the process of ensuring its effectiveness is a very complicated task. The EM approach involves the construction of a computational object – the *virtual prototype* (Adzhiev and Beynon 1994), which is based upon an agent-oriented methodology to intended to deal with multi-disciplinary engineering designs. This offers a great advantage in engineering projects by enabling the different agents (designers) to perceive and experiment with the system design through different perspectives which resemble different modes of observation.

a. Educational technology

Systems' modelling and simulation does not only serve industrial purposes; there exist many applications in education as well. By interacting with models of physical systems pupils are given the opportunity to actually experience the behaviour of an artefact which might not be possible to do so in real life. Such models may even allow pupils to conduct experiments which cannot be done inside a school laboratory.

EM as a discipline that encourages explanatory learning comprises a powerful tool in educational software. Exploration is one of the most dominant techniques which enable pupils to acquire a thorough perception about a particular subject. The experience as well as the knowledge gained from this exploration will most certainly enhance the level of detail of pupils' understanding in that subject.

Computer modelling can be used as a way to promote liberation of creativity and hence to motivate pupils to engage with the learning process (Beynon 1997). EM can also serve as an alternative to "orthodox" educational methods which usually result in loss of interest by the students. Also by adopting computer models as part of the educational framework can help in eliminating the need for the learning process to be dependent on the language.

3 Pendulum Simulation: A case study

For the purposes of this discussion, a simple pendulum model has been built. This model aims to simulate the motion of a bob suspended by a piece of string which can swing about a fixed pivot.

3.1 The model

The behaviour of the pendulum is specified by underlying laws of physics:

The angular frequency ( ) of the bob is given by:

$$= \sqrt{\frac{g}{l}} \qquad (1)$$

where g is the acceleration of gravity and l is the length of the string. The bob motion can be described by the following differential equation (Singiresu 1995):

$$\frac{d^2}{dt^2} + \frac{g}{l}\sin(\quad) = 0 \qquad (2)$$

where is the angle of deflection of the string from the perpendicular and t is the time. For determining given the time, the following equation has been used which is an approximation to the solution of the above differential equation:

$$(t) = a\sin(\quad t + \quad) \qquad (3)$$

where a is the amplitude of oscillation and is the phase. Such an approximation is sufficient enough for the purposes of this modelling study. If for some reason a more accurate numerical approximation is required then the Runge-Kutta algorithm can be used, but such an issue is beyond the scope of this model.

The user specifies the values of the variables that are needed to run the simulations. Those variables are: the length of the string, the acceleration of gravity, the mass of the bob and the amplitude of oscillation.

As it can be seen from the above equations, the angular frequency (1) is dependant on the length of the supporting string and the acceleration of gravity. This is a static dependency as these values do not change during the simulation. The user can manually change the length or the gravity during the simulations but it would also be an interesting extension if the bob was suspended by a spring which its length could vary with time.

On the other hand the position of the bob in respect to time is a dynamic dependancy. As it can be seen from (3) the current angle of deflection is dependant on a non-linear function of time angular freqeuncy, phase and amplitude. In order to demonstrate these dynamic dependancies in the model, the system includes a clock to emulate the notion of time.

There are some assumptions have been made for this model which are pretty common for this sort of simulations: There is no friction or any other kind of damping and there is perfect conservation of energy. Also the string is considered to be mass-less.

Within the pendulum model there are several identified agents: Pendulum, string, bob, simulation control, start, stop, reset and delay. For a more detailed account of the agents and observables regarding the physical properties and internal control of the model please refer to the model's LSD specification.

b. The model purpose

The purpose of such a model is to give the ability to the user to interact with the modelled artefact and experience the results of his or her actions. Through this experimentation the user can gain a thorough understanding of the behaviour of the system simulated. This model can serve the purposes of two categories of potential users one being a system's designer and the other one being a system's intended user or observer.

3.2.1 The designer-architect perspective

The designer needs the model to ensure that his proposed design reflects the specification of the artefact to be constructed. Using the pendulum model's visualisations and animation a designer may like to observe how well a particular approximation of the pendulum motion captures the actual pendulum behaviour. The author for instance, has experimented with two different approaches regarding the pendulum motion approximation: one was the approximation mentioned above and the other one was a simple harmonic motion approximation, which proved to be not so representative for the motion of an actual pendulum.

Even though such matter may not have any practical applications in real life, it has been mentioned in order to highlight the significance of modelling especially when complex systems are involved. System architects would like to assess their design without having to construct the actual system.

3.2.1 The educational perspective

Such a model can be used for educational purposes as well. It can be used to simulate the standard apparatus found in a school's physics laboratory for demonstrating the pendulum motion. Hence such models can be treated as means of enabling pupils to explore and experience the behaviour of say a real pendulum or consequently any other physical system. This can be found to be particularly helpful, especially for schools which do not have the appropriate apparatus for conducting experiments or don't have the ability to allow all pupils to be involved in an experiment. Such computer simulations can be distributed to pupils or made available to use in the school's computer labs so that the pupils are encouraged to conduct "virtual experiments" either for the purposes of an assignment or for the purpose of reviewing a particular experiment that has been conducted earlier in the laboratory.

An interesting exercise in a physics class for example, would be for pupils to be given this pendulum model and asked to investigate the factors which affect its period of oscillation. Interacting with the model the pupils can understand for instance how the length of the string or the acceleration of gravity affects the period of oscillation as well as to discover that the period does not depend on the mass of the bob. Also by altering the value of gravity pupils can see the difference between the motion of the pendulum on the surface of the earth and on the moon.

c. Visualisations

The physical laws are specified in tkEDEN, and DoNaLD and Scout are used for animating the pendulum as well as for displaying other information regarding the simulation variables onto the screen.

There is a fix pivot around which the suspended bob oscillates. As the bob is moving according to the equations described earlier, the forces that are currently acting on bob are illustrated by using arrows pointing to the direction that each of the forces are acting. These forces are the tension of the string s, the weight of the bob w, and the restoring force F (which is in fact a component of the tension s) and are determined by the following equations:

$$s = mg''cos \quad (4)$$

$$w = mg \quad (5)$$

$$F = mg''sin \quad (6)$$

where m is the mass of the bob, is the angle of deflection and g is the acceleration of gravity.

The user uses the control buttons (start, stop, reset) to control the simulation and enters the values of each variable in the appropriate data fields. Apart from the animation the values of period, angular frequency, restoring force, angle of deflection, weight, tension and time are displayed.

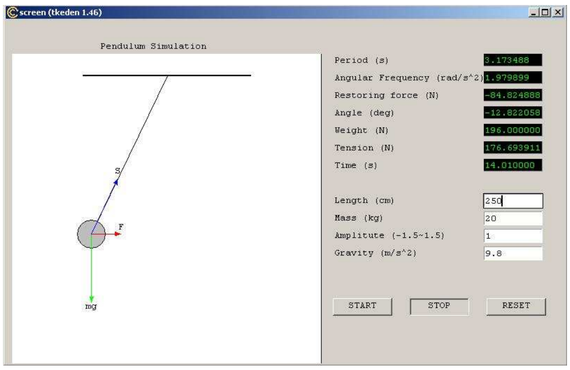

Figure I: A screenshot of the pendulum model

d. Further work

This pendulum model is just a simple example constructed for the purposes of this case study, to demonstrate the potentials of EM in the area of systems modelling and simulation. In real practice, models of this kind will involve much more complicated physical systems as well as more complex system dynamics.

Even within this simple model there is plenty of scope for further work. A possible augmentation of the model would be to include graphs which would be generated in real-time displaying how various quantities vary with time. An example would be a graph of the kinetic energy of the bob as it varies with time.

As mentioned earlier the string could be replaced by a spring so that its length can vary with time depending on the forces that act on it and consequently on the position and weight of the bob.

Friction and damping could be introduced to make the model more realistic. Such an extension would enable the observer to investigate various situations regarding the environment into which the pendulum in placed. For example it would be possible to see how the pendulum would move underwater.

An interesting extension would be to include some sort of control mechanism which will drive the pendulum according to a set point value. Even though the author has experimented with such an extension by using the %analog notation, it was not made possible to include this into the current version of the model due to the fact that the pendulum motion is a non-linear process, controlling which is not a straight-forward task.

4 Conclusions

This paper has highlighted the significance of Empirical Modelling in systems modelling and simulation. It has shown how the agent-oriented approach can enable the designers to review the abstract behaviour of a system and underlined the benefits that EM can offer to the field. Furthermore the aspects of educational technology and concurrent engineering were touched in order to emphasise the potentials of EM. Finally the model of a pendulum was built as a case study to acquire a practical appreciation of the capabilities of EM.

References

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